Fermi National Accelerator Laboratory

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Measurement of W and Z Production Cross-Sections in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

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MEASUREMENT OF W AND Z PRODUCTION CROSS-SECTIONS IN $p\bar{p}$ COLLISIONS AT $\sqrt{s} = 1.8$ TeV

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ABSTRACT

The cross sections for W and Z production in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV are measured using the DØ detector at the Fermilab Tevatron collider. The detected final states are $W \rightarrow e\nu_e$, $Z \rightarrow e^+e^-$, $W \rightarrow \mu\nu_\mu$, and $Z \rightarrow \mu^+\mu^-$. In the ratio of these measurements, many common sources of systematic error cancel and we measure $R = \sigma(p\bar{p} \rightarrow W) \cdot Br(W \rightarrow l\nu) / \sigma(p\bar{p} \rightarrow Z) \cdot Br(Z \rightarrow l^+l^-)$. Assuming standard model couplings, this result is used to determine the width of the W boson and to set a limit on the decay $W^+ \rightarrow t\bar{b}$.

1. Introduction

The cross-sections times branching ratios for $p\bar{p} \rightarrow W$ and $p\bar{p} \rightarrow Z$ with decays into final states with electrons or muons are measured using the DØ detector. In the ratio of these measurements, many common sources of systematic error cancel and we measure

$$R = \frac{\sigma(p\bar{p} \rightarrow W + X) \cdot B(W \rightarrow l\nu)}{\sigma(p\bar{p} \rightarrow Z + X) \cdot B(Z \rightarrow l^+l^-)}.$$

This ratio is of interest since it can be expressed as the product of calculable or well-measured quantities:

$$R = \frac{\sigma(p\bar{p} \rightarrow W + X)}{\sigma(p\bar{p} \rightarrow Z + X)} \frac{\Gamma(W \rightarrow l\nu)}{\Gamma(Z \rightarrow l^+l^-)} \frac{\Gamma(Z)}{\Gamma(W)}.$$

This gives the most precise measurement of $\Gamma(W)$. A width measurement which exceeds the standard model value might indicate non-standard decays of the W.

2. The DØ Detector

The DØ detector[1] consists of three major subsystems: central tracking detectors, nearly hermetic liquid argon calorimetry, and a muon spectrometer. The central tracking system is used to identify tracks in the psuedorapidity range $|\eta| \leq 3.5$. The calorimeter covers the region up to $|\eta| \leq 4$ with energy resolution for electrons approximately $15\%/\sqrt{E}$. The muon system consists of drift chambers and magnetized iron toroids.

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*Representing the DØ Collaboration.

3. Electron Channel Cross-sections

The $W \to e\nu_e$ and $Z \to e^+e^-$ candidates were collected on a single trigger consisting of a two levels: the hardware trigger required electromagnetic energy above threshold (usually 10 GeV) in a .2 x .2 (η x ϕ) tower. The software trigger required $E_T \geq 20$ GeV and made loose shower shape and isolation cuts.

Offline electrons were required to have mostly electromagnetic energy, a shower shape consistent transversely and longitudinally with an electron, be isolated from other activity in the calorimeter, and be matched with a central detector track. Fiducial cuts of $|\eta| \leq 1.1$ or $1.5 \leq |\eta| \leq 2.5$ ensured a good trigger, good energy resolution, and low background.

The $W \to e\nu_e$ candidates satisfied $E_T > 25$ GeV and $\not{E}_T > 25$ GeV, resulting in a sample of 10346 candidates. The $Z \to e^+e^-$ candidates had two electrons with $E_T \geq 25$ GeV, one of which satisfied all the $W \to e\nu_e$ cuts, and the other passed all except the track match cut. There was an invariant mass cut of $75 \leq M_{inv} \leq 105$ GeV, creating a sample of 782 candidates.

Electron efficiencies are determined from the $W \to e\nu_e$ sample with a harder $\not{E}_T$ cut and from the $Z \to e^+e^-$ sample. The $W \to e\nu_e$ backgrounds are estimated separately either from data (QCD) or Monte Carlo ($W \to \tau \to e$ and $Z \to e^+e^-$). The $Z \to e^+e^-$ background is estimated by fitting the invariant mass peak to a Breit-Wigner convoluted with the detector resolutions plus a linear background. Luminosity for this trigger was $\int Ldt = 12.4 \pm 1.5\ \mathrm{pb}^{-1}$. Table 1 gives the preliminary values of the cross-sections.

Table 1. Measured W and Z Cross-sections

	$W \to e\nu_e$	$Z \to e^+e^-$	$W \to \mu\nu_\mu$	$Z \to \mu^+\mu^-$
Number of Events	10346	782	1665	77
Acceptance	46.1 ± 0.9 %	36.4 ± 0.5 %	25.1 ± 0.7 %	6.7 ± 0.4 %
Trig + Sel Eff.	73.7 ± 1.8 %	74.6 ± 3.0 %	22.4 ± 2.6 %	53.8 ± 5.0 %
Total Bkgd	5.9 ± 0.7 %	5.2 ± 2.3 %	22.1 ± 1.9 %	10.1 ± 3.7 %
Luminosity	$12.4 \pm 1.5\mathrm{pb}^{-1}$		$11.1 \pm 1.3\mathrm{pb}^{-1}$	
$\sigma \cdot$ B(nb)	2.32	0.220	2.09	0.174
Stat. Err.	$\pm$ 0.02	$\pm$ 0.008	$\pm$ 0.07	$\pm$ 0.022
Syst. Err.	$\pm$ 0.07	$\pm$ 0.011	$\pm$ 0.22	$\pm$ 0.018
Lum. Err.	$\pm$ 0.28	$\pm$ 0.026	$\pm$ 0.25	$\pm$ 0.021

4. Muon Channel Cross-sections

The $W \to \mu\nu_\mu$ and $Z \to \mu^+\mu^-$ trigger consisted of two hits-in-road searches at the hardware level (first a coarse road, then a fine road, with an effective P_T cut of 7 GeV). The software trigger did track finding and reconstruction and required at least one muon with $P_T \geq 15$ GeV.

Offline tracks ("loose" muons) were confirmed by energy in the calorimeter and required to pass through the central iron ($|\eta| \leq 1.0$) and through a minimum magnetic field ($\int B \cdot dl \geq 2\,Tm$). "Tight" muons were defined satisfy the loose requirements plus have a matching track in the central detector, have a good quality fit to the vertex point, central detector track and muon track, be in time with beam crossing, and be isolated in the calorimeter.

The $W \to \mu\nu_\mu$ candidates have a tight muon and satisfied kinematic cuts of $P_T \geq 20$ GeV and $\not{E}_T \geq 20$ GeV for a sample of 1665 candidates. The $Z \to \mu^+\mu^-$ candidates have one tight muon and a second loose or tight muon. Kinematic cuts of $P_T{}^{\mu 1} \geq 20$ and $P_T{}^{\mu 2} \geq 15$ GeV yielded 77 candidates.

Muon efficiencies are determined from the $Z \to \mu^+\mu^-$ sample. The $W \to \mu\nu_\mu$ and the $Z \to \mu^+\mu^-$ backgrounds are estimated from data for the QCD and cosmic channels, and from Monte Carlo for the $Z \to \mu^+\mu^-$, $Z \to \tau^+\tau^-$, $W \to \tau \to \mu$, and Drell-Yan backgrounds. The luminosity for this trigger was $11.1 \pm 1.3\mathrm{pb}^{-1}$ and the preliminary cross-sections are reported in table 1. The electron and muon cross-sections are compared to other measurements in figure 1.

5. Ratio Measurements and $\Gamma(W)$

The ratio $R = \sigma \cdot \mathrm{B}(W \to l\nu)/\sigma \cdot \mathrm{B}(Z \to l^+l^-)$ is of interest since it can be expressed as the following combination of precisely measurable or calculable quantities:

$$R \equiv \frac{\sigma B(W \to \mu\nu)}{\sigma B(Z \to \mu\mu)} = \frac{\sigma(\mathrm{p\bar{p}} \to W + X)}{\sigma(\mathrm{p\bar{p}} \to Z + X)} \frac{\Gamma(W \to l\nu)}{\Gamma(Z \to l^+l^-)} \frac{\Gamma(Z)}{\Gamma(W)}. \qquad (1)$$

The measured value for the Z width is obtained from the LEP experiments[2]

$$\Gamma(Z) = 2.487 \pm 0.010 \text{ GeV/c}^2.$$

The ratio of the W and Z leptonic decay widths is taken from its theoretical value[3]

$$\frac{\Gamma(W \to l\nu)}{\Gamma(Z \to l^+l^-)} = 2.70 \pm 0.01.$$

The ratio of the W to Z production is determined using the complete $O(\alpha_s^2)$ calculation[4] convoluted with various parton distribution functions[5] to obtain

$$\frac{\sigma(\mathrm{p\bar{p}} \to W + X)}{\sigma(\mathrm{p\bar{p}} \to Z + X)} = 3.34 \pm 0.03$$

where the quoted error is dominated by the uncertainty on the W mass and systematic differences in the structure functions.

We take the weighted average of the muon and electron channels' measurements of R:

$$\begin{aligned} R^e &= 10.54 \pm 0.39(stat) \pm 0.55(syst), \\ R^\mu &= 12.0^{+1.8}_{-1.4}(stat) \pm 1.0(syst), \\ R^{e\mu} &= 10.78^{+0.68}_{-0.60}(stat + syst). \end{aligned}$$

Combining this average value with equation 1 yields the total width of the W

$$\Gamma(W) = 2.08 \pm 0.12(stat + syst) \pm 0.02(theory + LEPsyst)\ \text{GeV}.$$

This result can be compared with the Standard Model prediction[6] of

$$\Gamma(W) = 2.09 \pm 0.02\ \text{GeV}$$

for $M_t > M_b + M_W$ where M_t, M_b and M_W are the masses of the top quark, bottom quark and W boson, respectively.

We can set a limit on the decay of the W into new quark pairs. If the W couples to a new quark and to the b quark with standard model coupling, a limit on the mass of this quark is set:

$$m_q > 56\ \text{GeV at 95\% CL.}$$

This limit applies independent of any assumptions of decay modes of the top quark and is illustrated in figure 2.

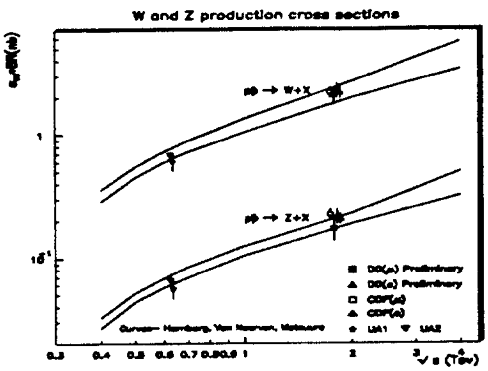

Fig. 1. W and Z cross-sections

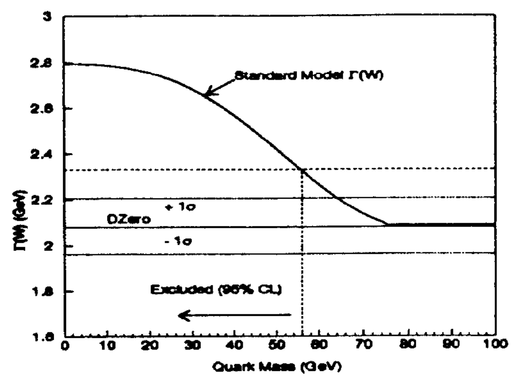

Fig. 2. Quark Mass Limit

6. Summary

DØ has measured the production cross-sections for W and Z in $p\bar{p}$ at $\sqrt{s} = 1.8$ TeV . We report preliminary results for those cross-sections and for their ratio, $R^{e\mu} = 10.78^{+0.68}_{-0.60}$. This yields a measurement of the width of the W, $\Gamma(W) = 2.08 \pm 0.12(exp) \pm 0.02(thy)$ GeV, and a limit on a new quark $m_q > 56$ GeV at 95% confidence level.

References

1. S. Abachi *et al.*, NIM **A338**, 185 (1994).
2. The LEP collaborations: ALEPH, DELPHI, L3 and OPAL, Phys. Lett. **B276**, 247 (1992)
3. W. F. Hollik, Firtschr. Phys. **38**, 165 (1990)
4. R. Hamberg, W. L. Van Neerven and T. Matsuura, Nucl. Phys. **B359**, 343, (1991).
5. S. Lami and D. Wood, DØ internal Note # 1462, 1992 (Unpublished).
6. T. Alvarez, A. Leites and J. Terrón, Nucl. Phys. **B301**, 1 (1988).